Principles
Learning Objectives

Learn how to use basic principles to improve planning, implementation and decision-making:

- Soil heterogeneity at 2 spatial scales makes it difficult to correctly interpret data results
  - Those spatial scales are micro-scale and short-scale
  - Heterogeneity at these scales can cause data variability → costly decision errors
- Micro-scale heterogeneity is managed by the *improved lab sample processing ISM requires*
- Short-scale spatial heterogeneity is managed by the *field incremental sampling of ISM*

Report Documentation Page

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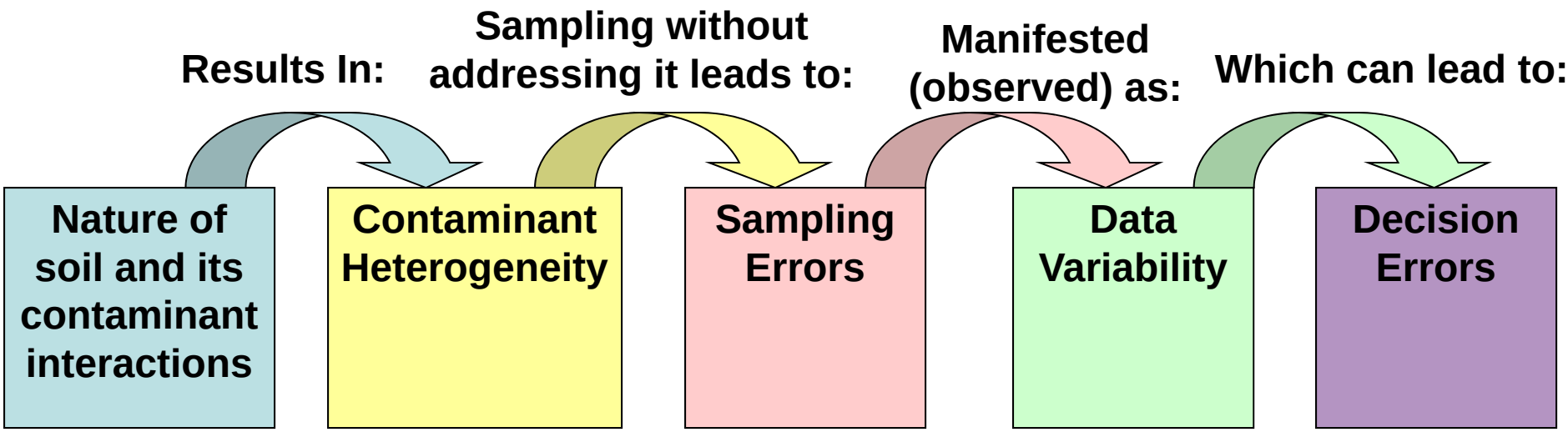
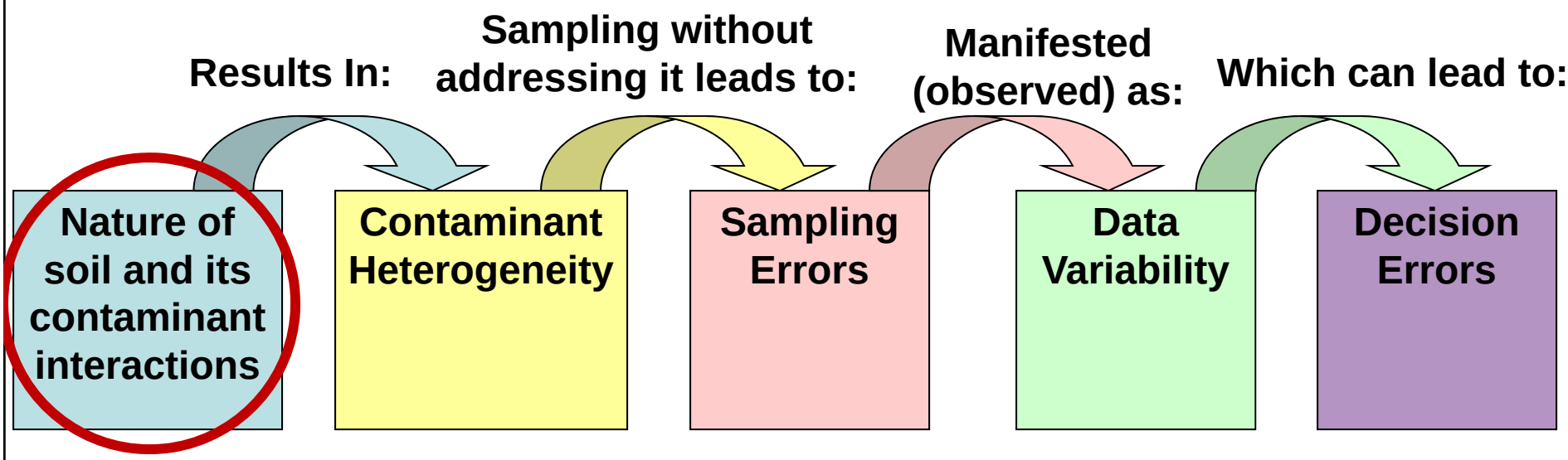
How Soil Heterogeneity Can Cause Decision Errors: Navigation Pane



- Heterogeneity: the condition of being non-uniform
- The heterogeneous nature of contaminants in soils increases the chances of decision error

ITRC, ISM-1, Section 2.1

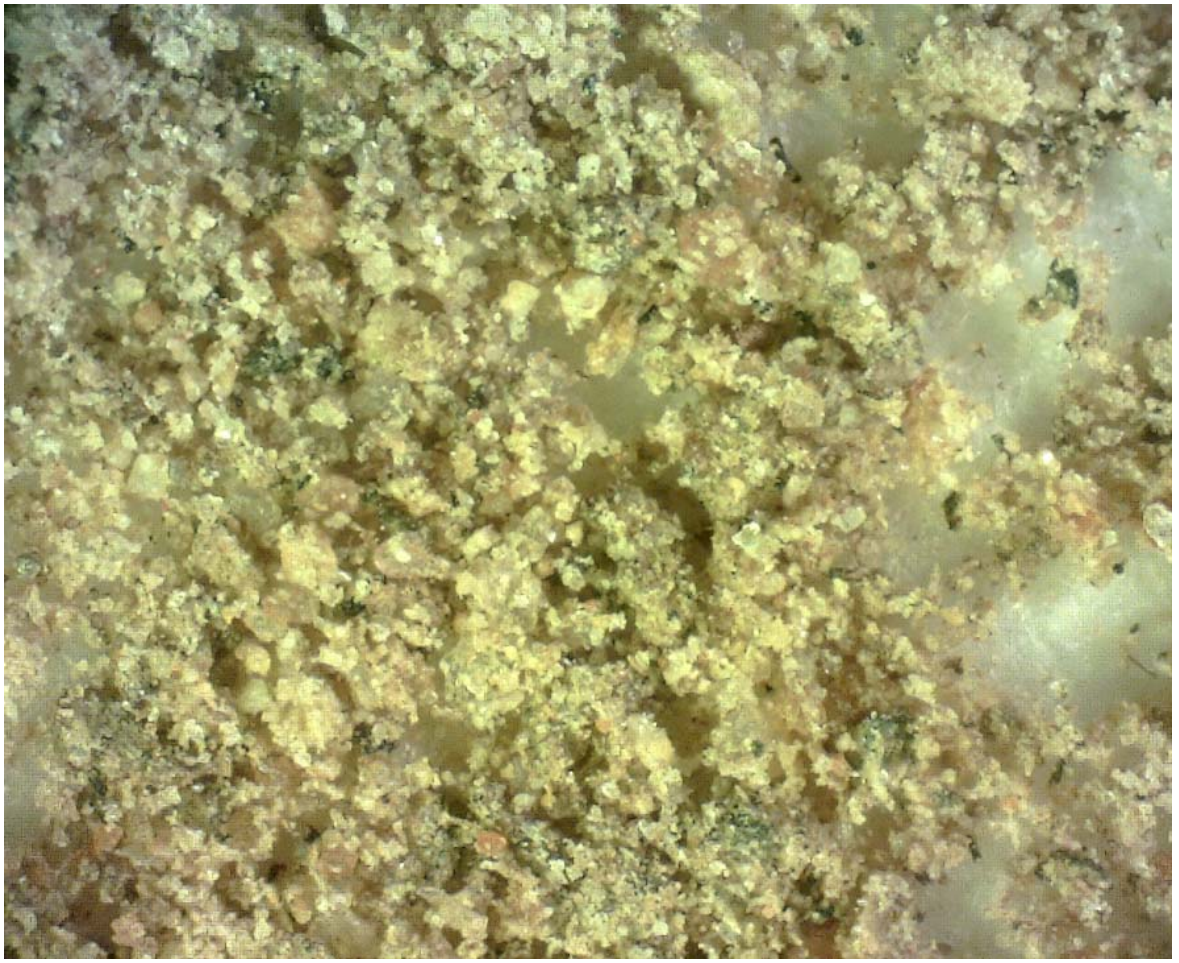
Soil is a Complex Particulate Material



- All soil is heterogeneous in composition
- Typical mixing/stirring cannot make soil uniform

Micro-Scale Variation in a Homogeneous-Looking Soil

Photo credit: Deana Crumbling



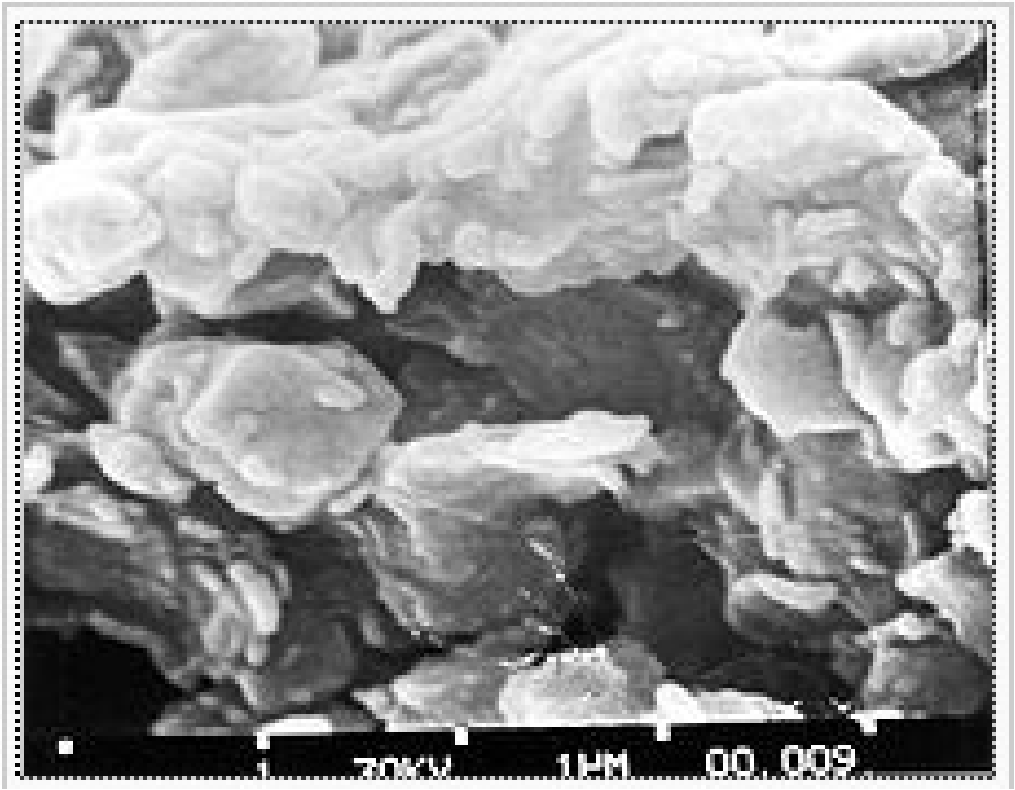
A sandy soil, showing variation in particulate size and mineral content (10X magnification)

Soil Particle Composition

Individual soil particles can have inorganic and/or organic components

- Many contaminants adhere to the surfaces of certain minerals
- Organic carbon is composed of complex molecules that can act as molecular sponges

Interaction between contaminants and soil particles



Electron microscope photograph of smectite clay – magnification 23,500

- Contaminants are attracted to certain particles
- Smallest particles usually have the largest surface area
  - Clays (see photo)
  - Iron (hydr)oxides
- Attraction mechanisms
  - ionic charges
  - Van der Waals forces

ITRC, ISM-1, Section 2.2.1.1

Photo credit: USGS, 2006

Particles with high contaminant loadings are called “Nuggets”

- Contaminants adsorbed to distinct particles form “nuggets” of high concentration

“the iron in a cubic yard of soil [1-1.5 tons] is capable of adsorbing 0.5 to 5 lbs of soluble metals …or organics” (Vance 1994).

Arsenic (whitish color) sorbed to iron hydroxide particles

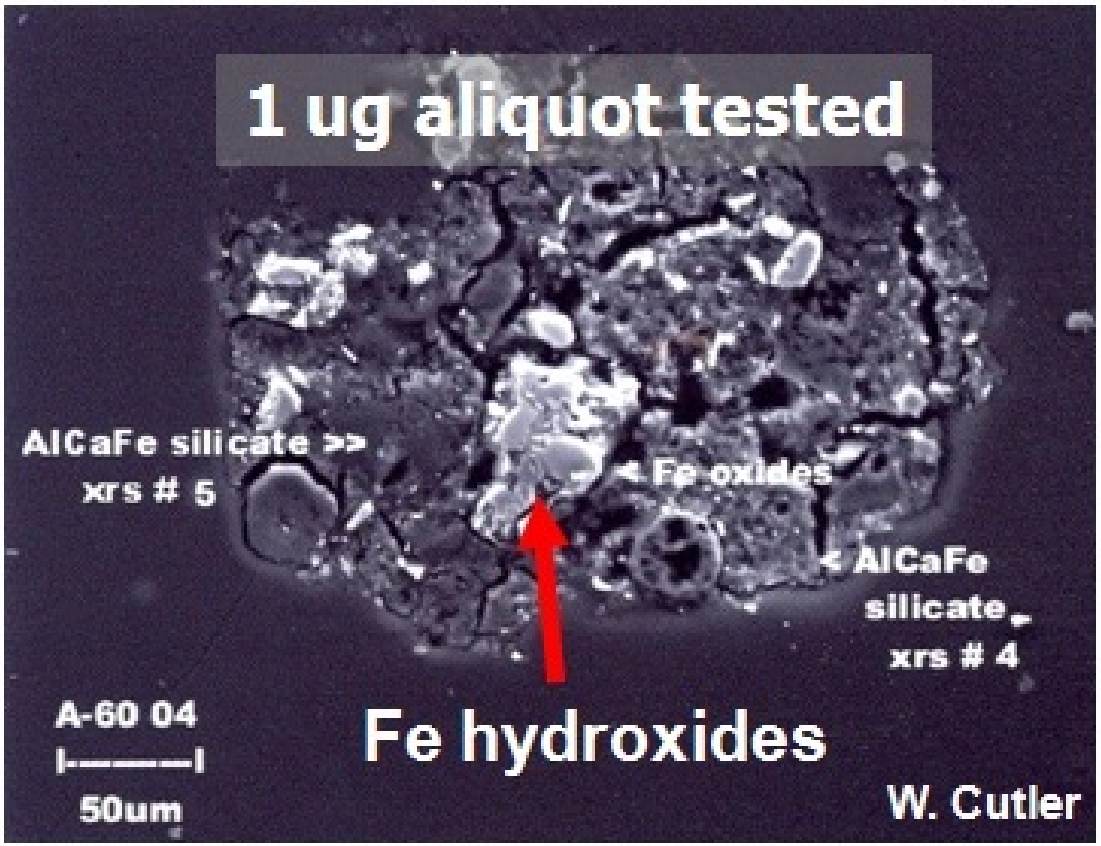


Photo courtesy of Roger Brewer, HDOH

ITRC, ISM-1, Section 2.2 hyperlinks

Contaminants can exist as Particles

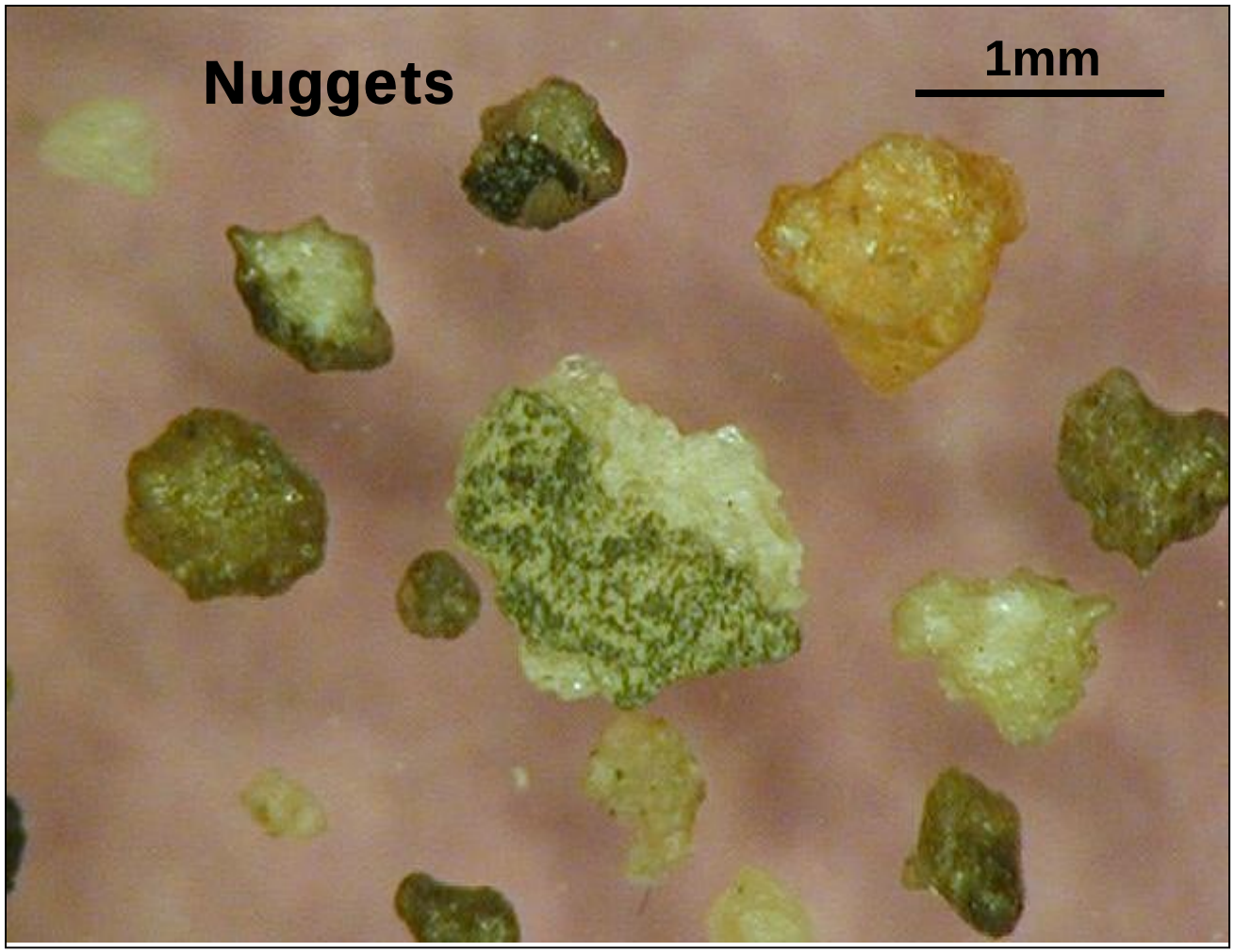
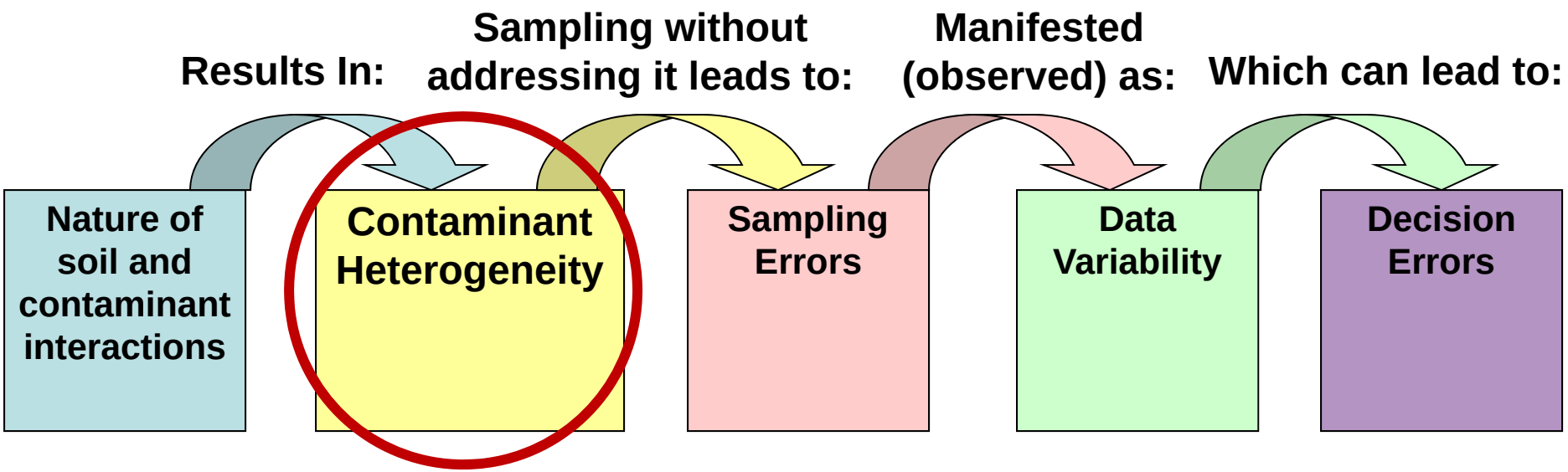


Photo courtesy of Alan Hewitt (USACE)

Tiny chunks of pure RDX/TNT explosive isolated from a soil sample

Particulates in Solid Matrices Create "Micro-Heterogeneity"



- "Micro-heterogeneity" is non-uniformity within the sample jar
- Important because contamination is heterogeneous **at the same spatial scale as sample analysis**

ITRC, ISM-1, Section 2.5.2

Micro-Scale Heterogeneity Makes Contamination Hard to "Read"

- Micro-Scale heterogeneity interferes with interpreting analytical results
- If contaminant distribution is not uniform in the sample jar, how can we be sure that analytical data represent the contents of the jar, much less the field?
  - Huge mismatch between scale of decision-making and scale of sample analysis

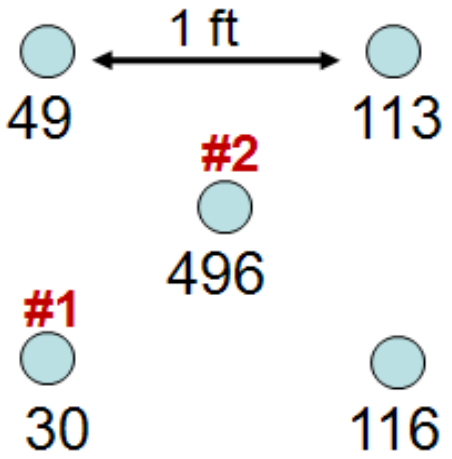
Metals Analysis on 1 Gram of Soil Guides Decisions on Tons

vs.

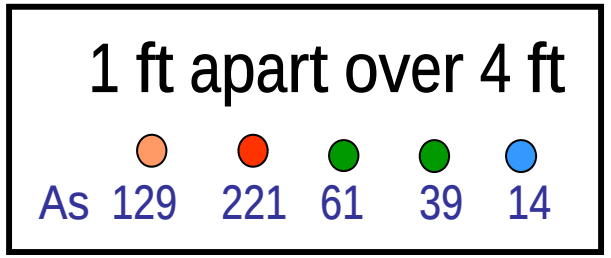
Photo credits:
Roger Brewer, HDOH

Short-Scale Field Heterogeneity: Co-located Samples

- Shortest spatial scale in the field measured by "co-located samples" (inches to a few feet apart)
- Samples anticipated to be "equivalent," but often give very different results
- Chance governs exact location where soil is scooped
  - Therefore, ***chance*** can determine decision outcome!
- *ISM addresses the problems of both micro- and short-scale heterogeneity*



Set of co-located samples for uranium (mg/kg)



Arsenic in residential yard transect (mg/kg)

ITRC, ISM-1, Section 2.2.2

Long-Scale Heterogeneity is Generally at the Scale of Decision-Making

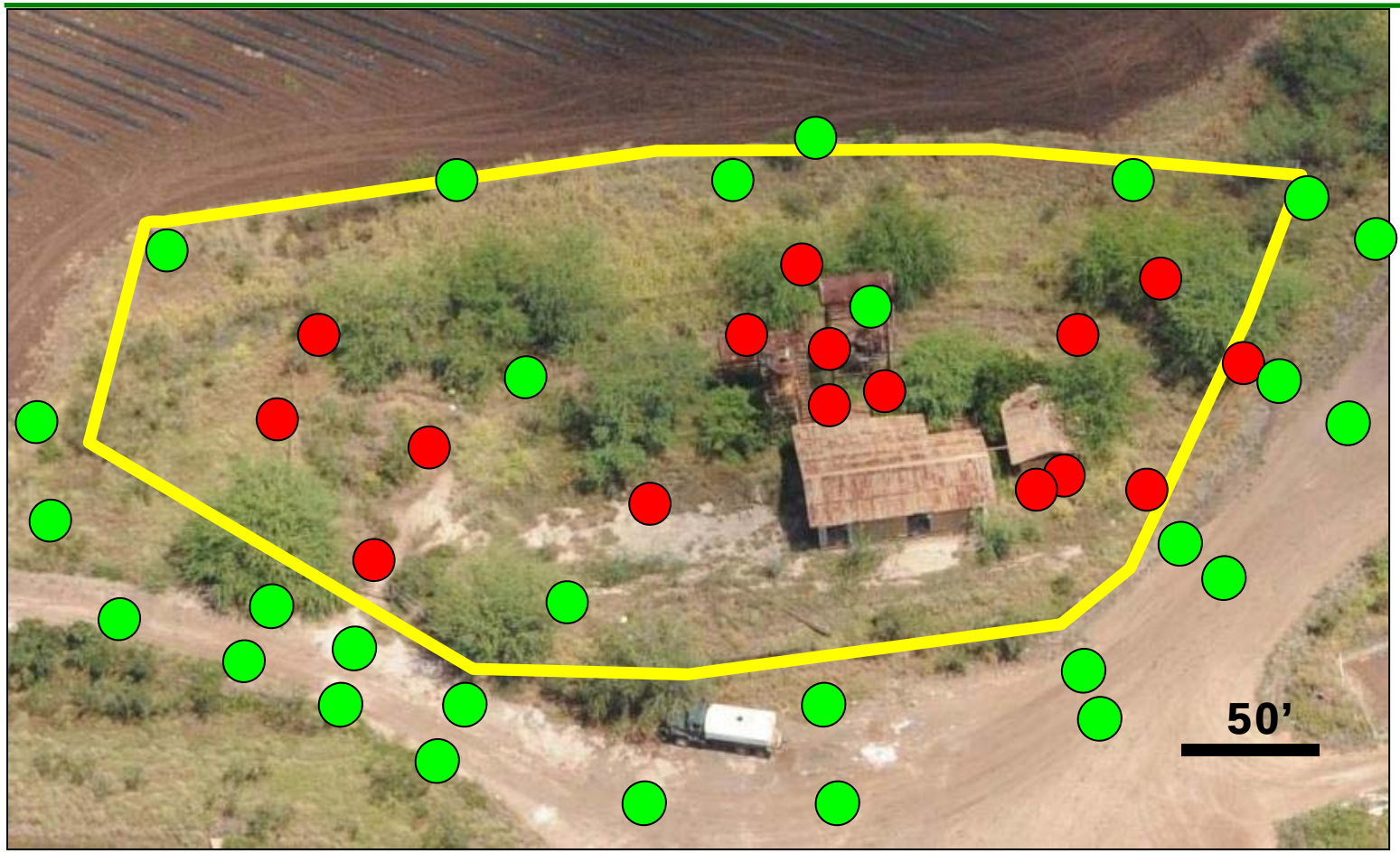
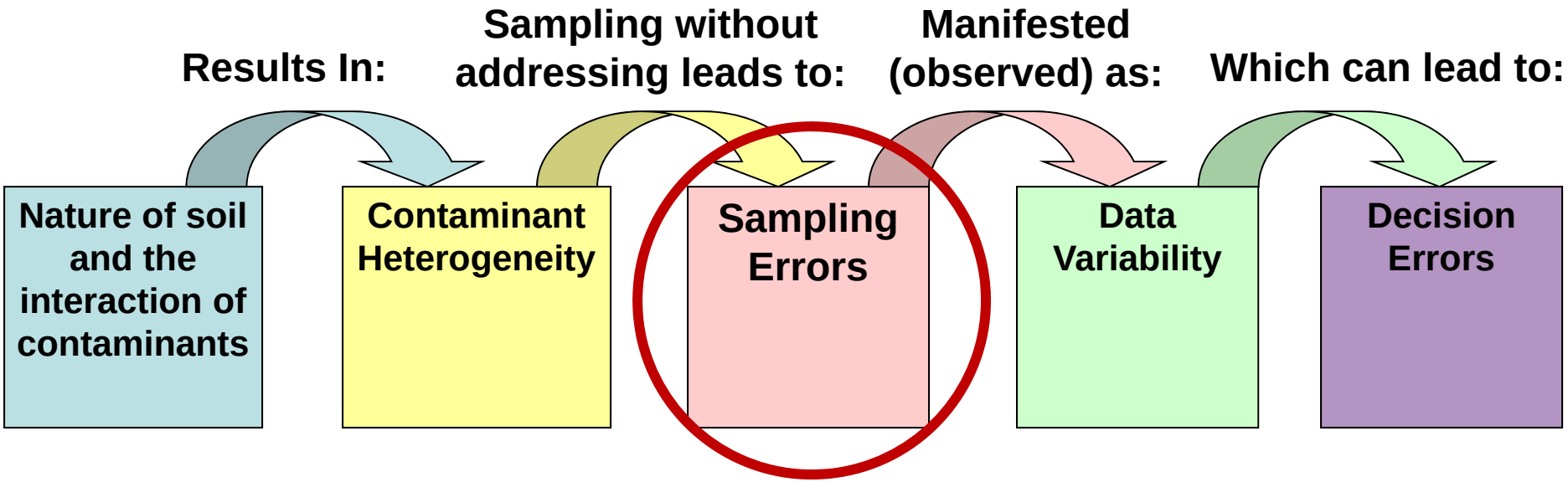


Figure credit: Roger Brewer, HDOH

Results for an actual sampled property. Green circles denote concentrations below the action level; red circles are above the action level.

Heterogeneity Causes Sampling Errors



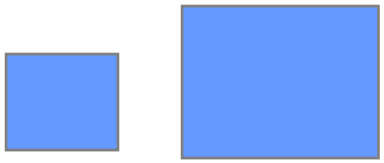
- Sampling error occurs when samples fail to represent the original targeted population
- Need the concept of "sample support" (the physical dimensions and mass of the sample)

ITRC, ISM-1, Section 2.3.2, 2.4.1.1 and 2.2 hyperlinks

Concentration is a Function of Sample Support and Contaminant Mass

Common assumption

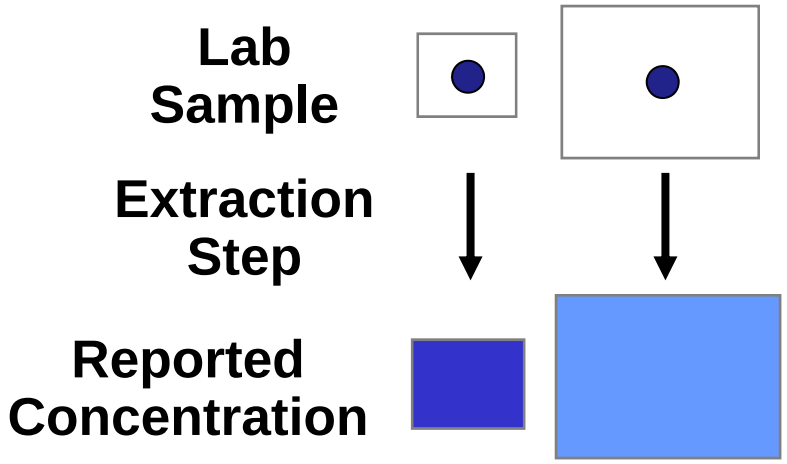
The amount of soil analyzed makes no difference to what results are obtained.



Concentration = contaminant mass (mg) ÷ the soil mass (kg)

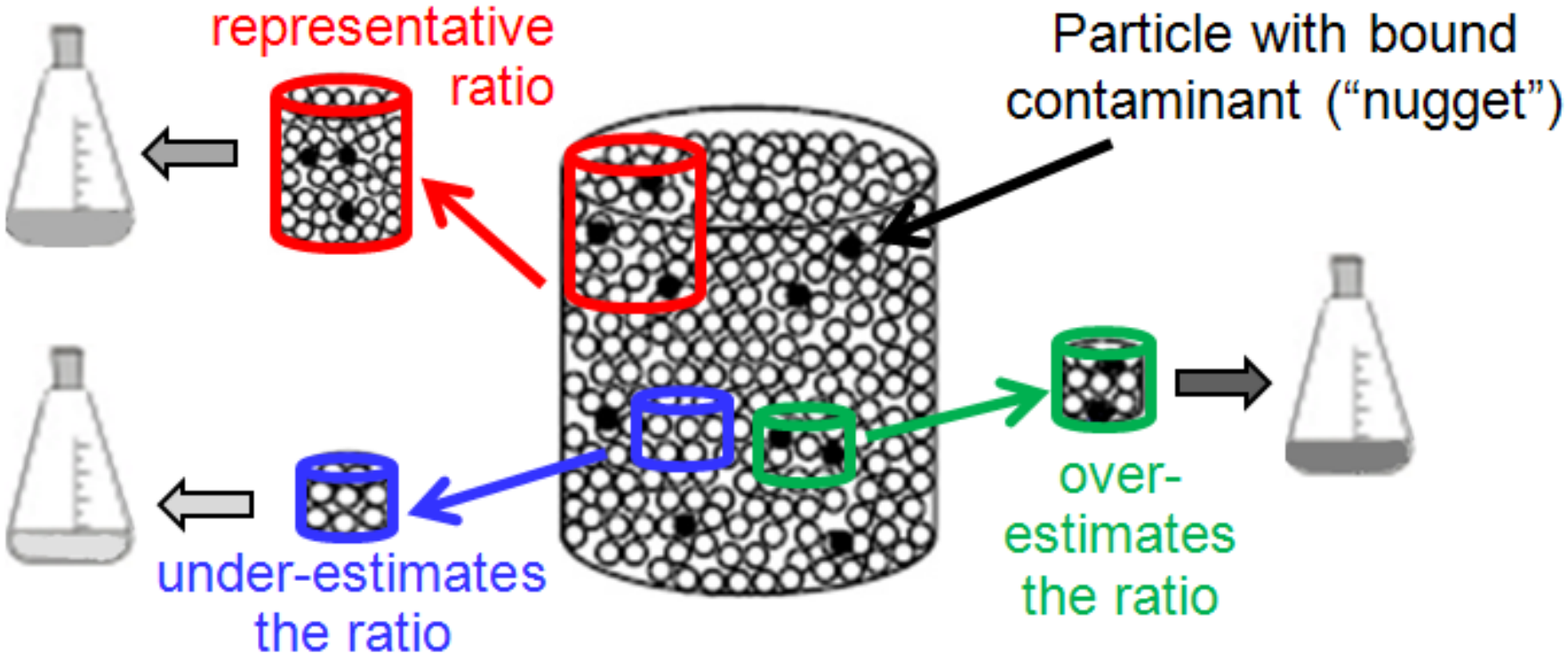
Assumption wrong for solids

Can have the **same** contaminant mass (blue), BUT in different **sample** masses (white)…



…get **different** concentration results

Smaller Sample Supports are More Prone to Sampling Error than Larger Ones



- Illustration of sampling error: For the blue and green samples, the proportion of nuggets in the samples do not represent the nugget proportion of the population (the large container)

Change the Sample Support and Change the Concentration

Concentration = contaminant mass ÷ the soil mass

Arsenic mass of 5 ng in a sample support of 1 µg of other soil minerals: arsenic conc = 5000 mg/kg

Analyze an As-Fe-OH grain by itself and arsenic conc might be 100,000 mg/kg (10%) or more.

Arsenic (As) sorbed to iron hydroxide (Fe-OH) mineral grains

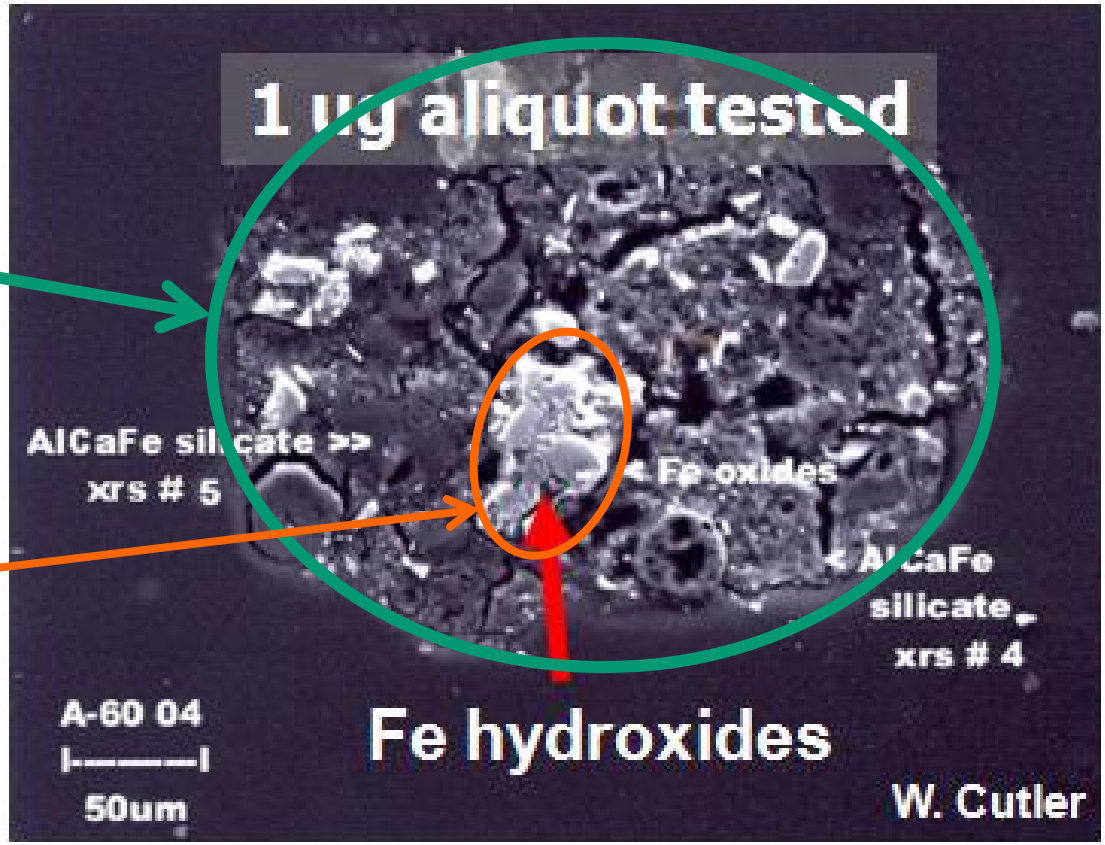


Figure courtesy of Roger Brewer

ISM Addresses Sample Support

Same As-Fe-OH grains in 1 gram of other minerals: arsenic conc = 0.005 mg/kg

Photo credit: Deana Crumbling

A lack of control over sample support during lab subsampling and in the field is a primary cause of sampling error and data variability.

ISM explicitly manages sample support!

ITRC, ISM-1, Sections 5 and 6

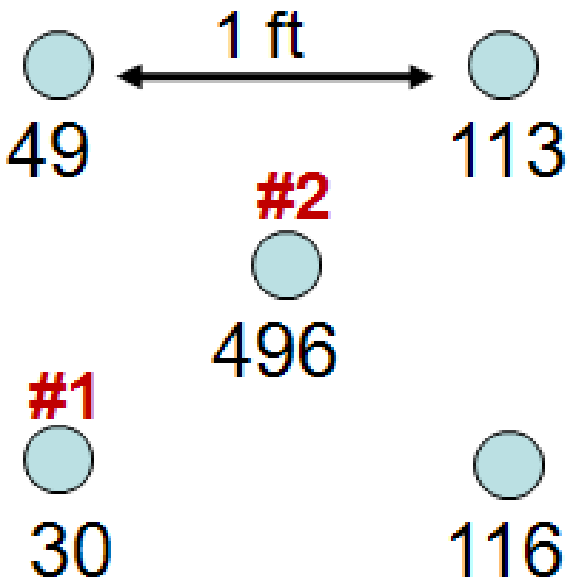
Ways to Reduce Sampling Error When Sampling a Jar

- ISM stresses the importance of sample support and techniques to reduce sampling error
  - Reduce particle size (grinding)
  - Increase sample support (i.e., extract a larger analytical sample mass)
  - Take many increments to make up the analytical subsample ("incremental subsampling")
    - Use equipment like rotary splitters →

ITRC, ISM-1, Table 3-1 and 6.2.2.5 to 6.2.2.7

Reducing Short-scale Sampling Error

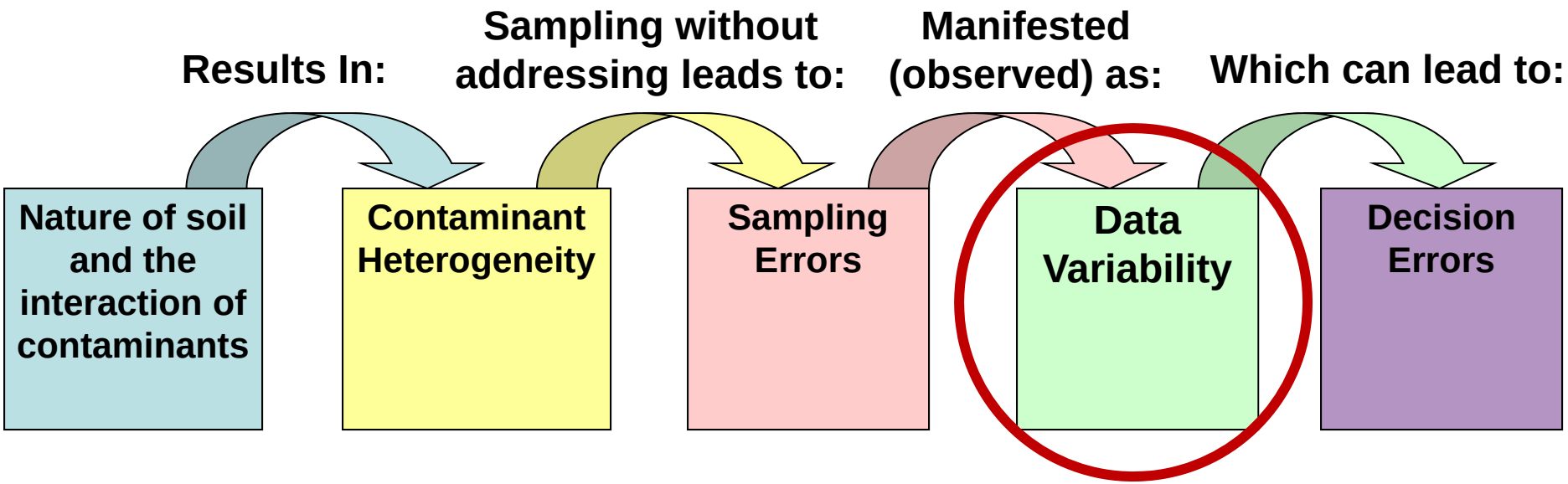
- Goal is to get THE concentration for a target soil volume, so…
  - IDEAL: analyze whole volume as a single sample
  - PRACTICAL: Increase sample support and spatial coverage of the DU by taking many increments and combining them into one sample
- *This is what ISM does*



Set of co-located samples for uranium

ITRC, ISM-1, Section 2.6.2.1

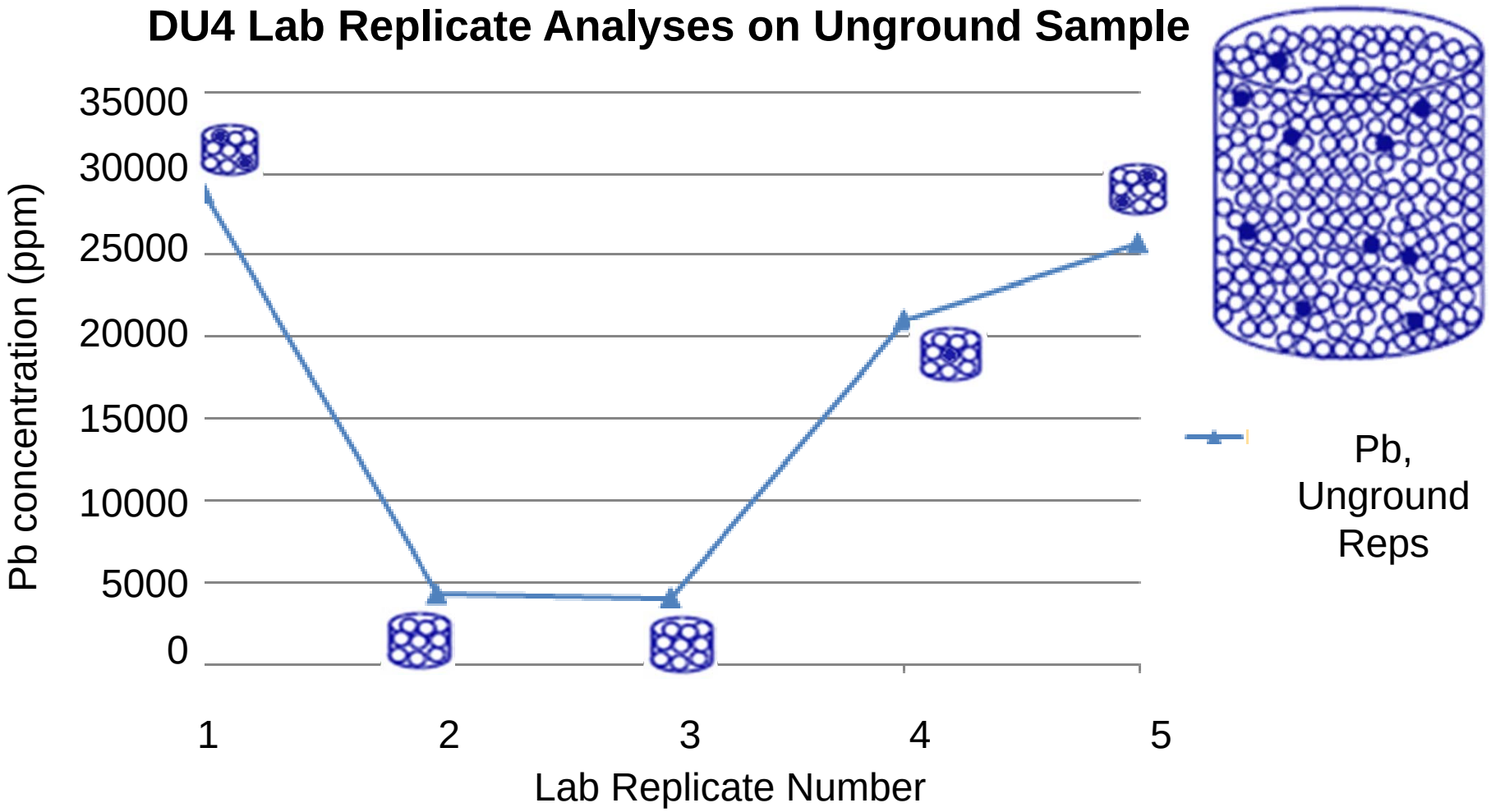
Sampling Error Causes Data Variability



- Sampling errors contribute to data variability

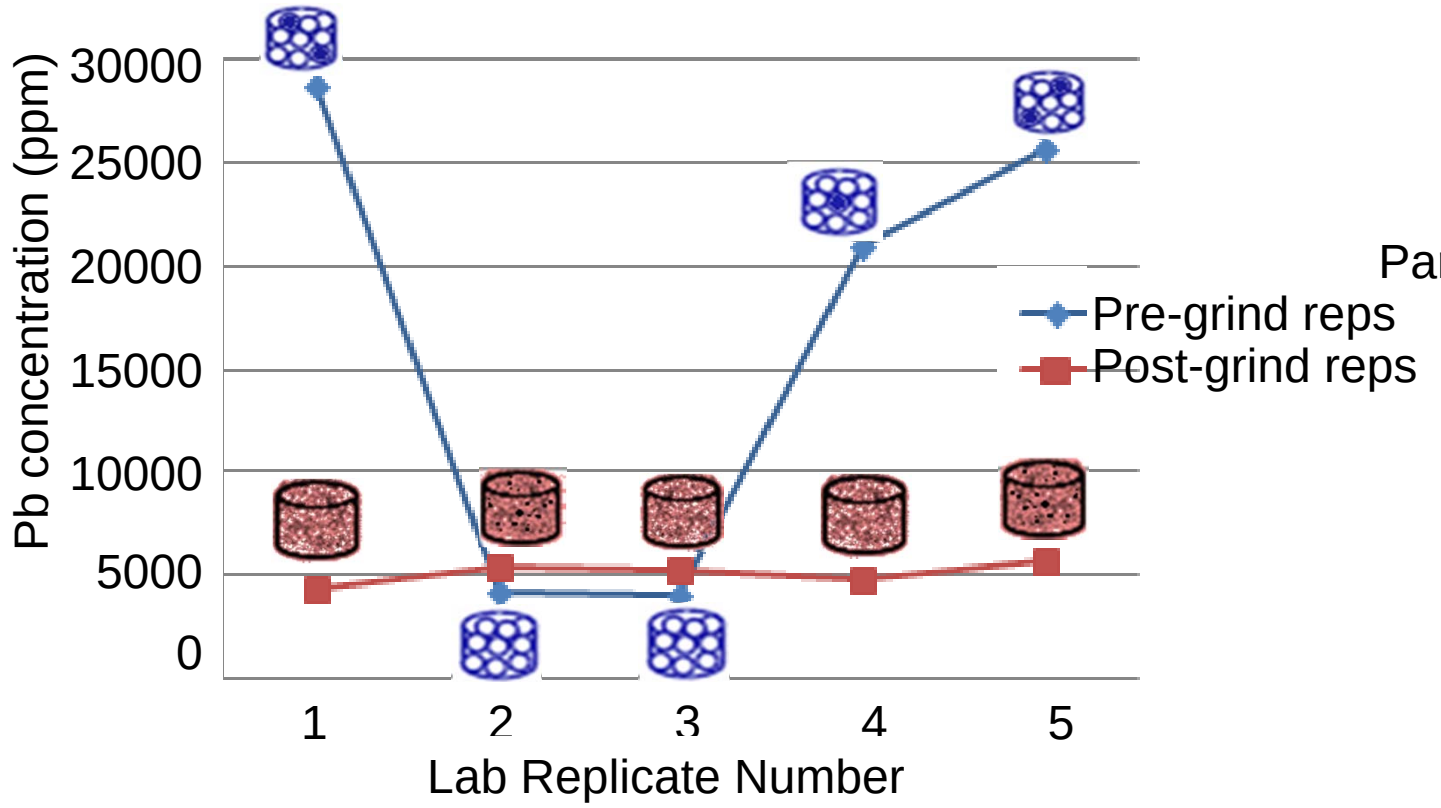
ITRC, ISM-1, Sections 2.4.1.3

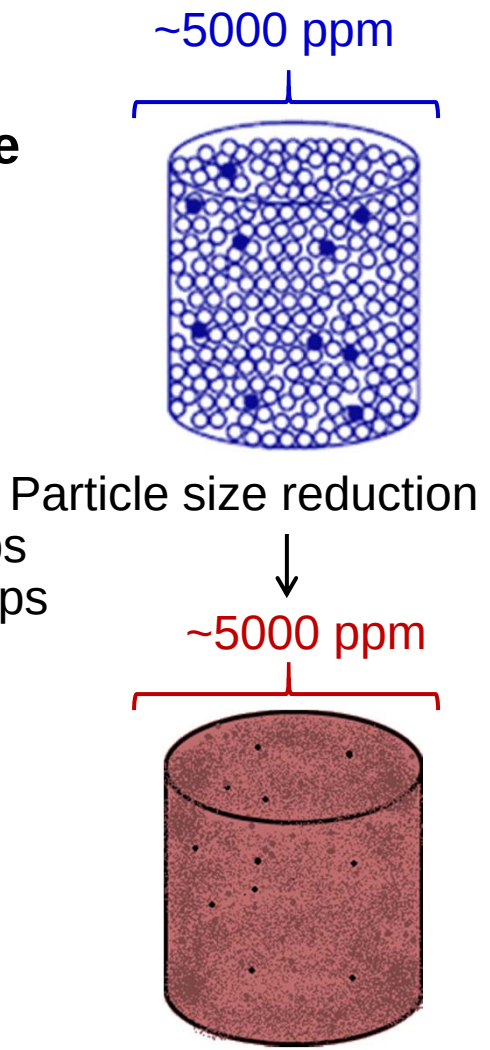
Study Data for Pb: 5 Laboratory Replicate Subsamples from Same Jar



Same Soil Sample After Grinding

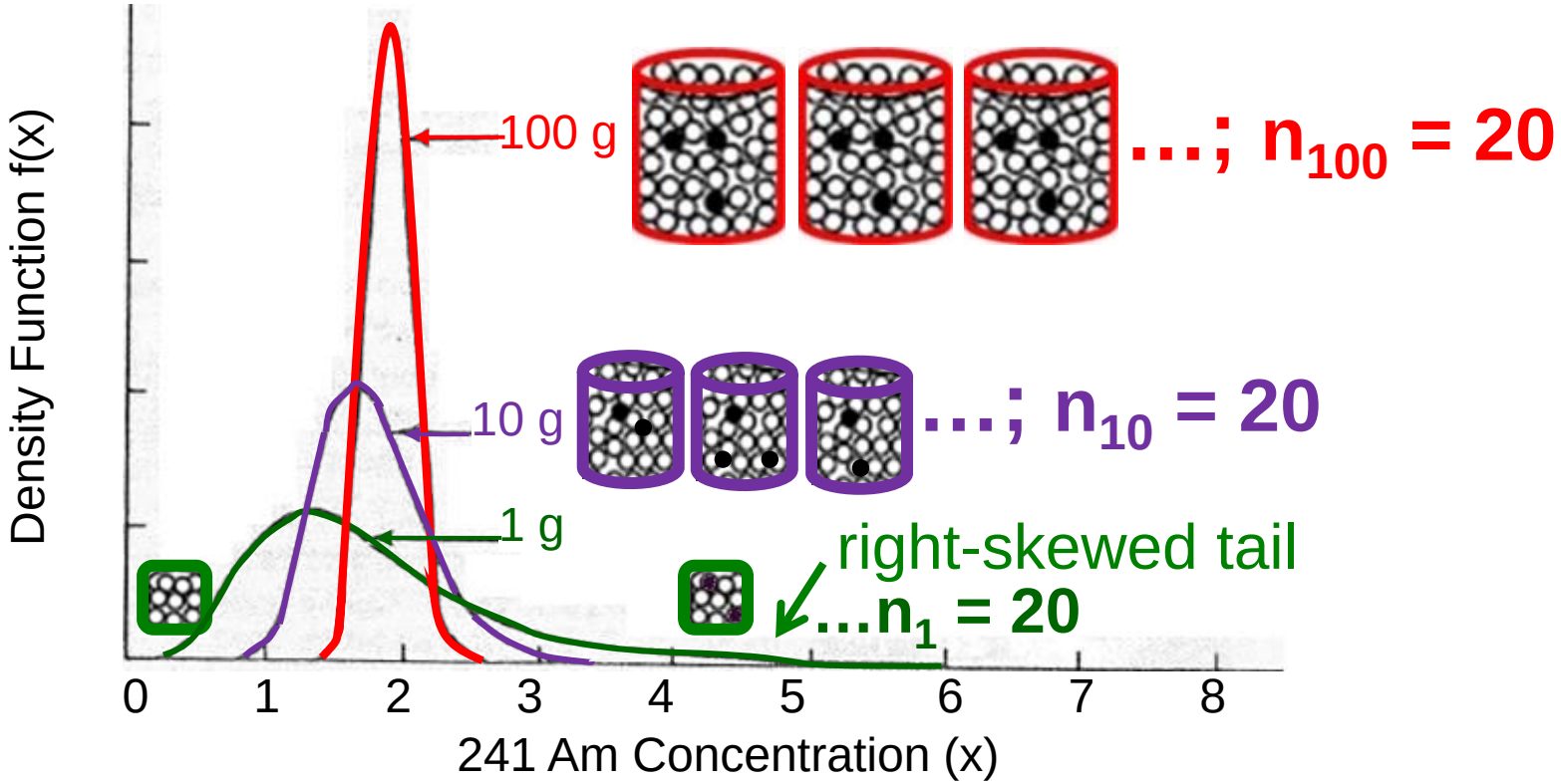
Pre-grind range: Pb 4000-29000 Post-grind range: Pb 4360-5660





Sample Support Influences Statistical Distributions

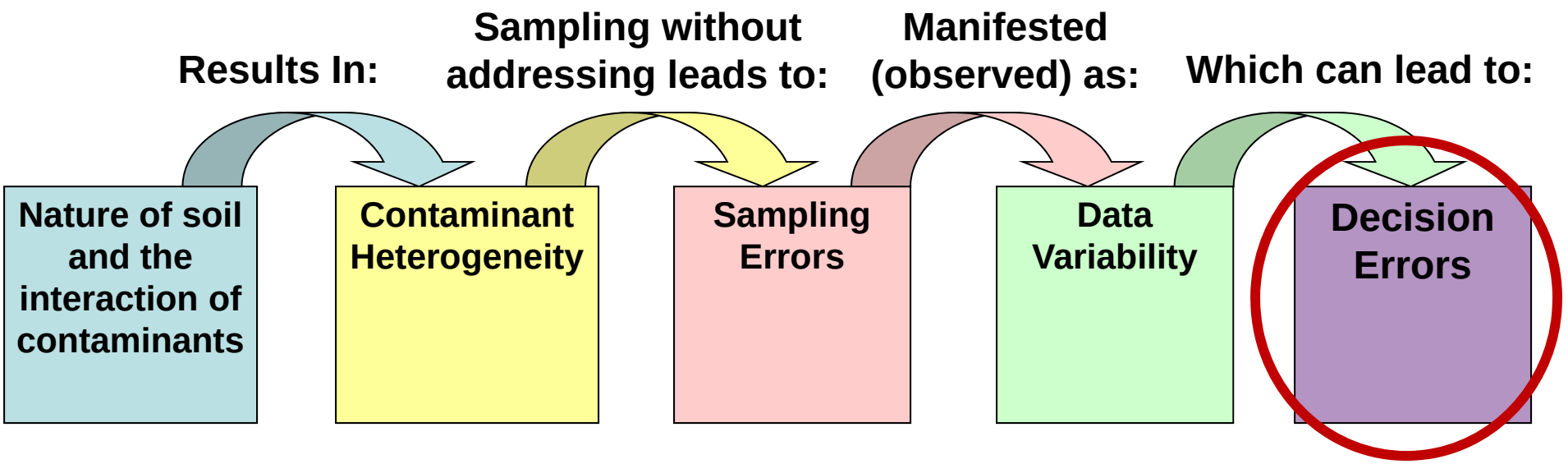
Small sample supports contribute to skewed statistical distributions



ITRC, ISM-1, Section 2.4.1.3

Adapted from DOE study (Gilbert, 1978)

Concepts Underlying ISM: Avoiding Decision Error

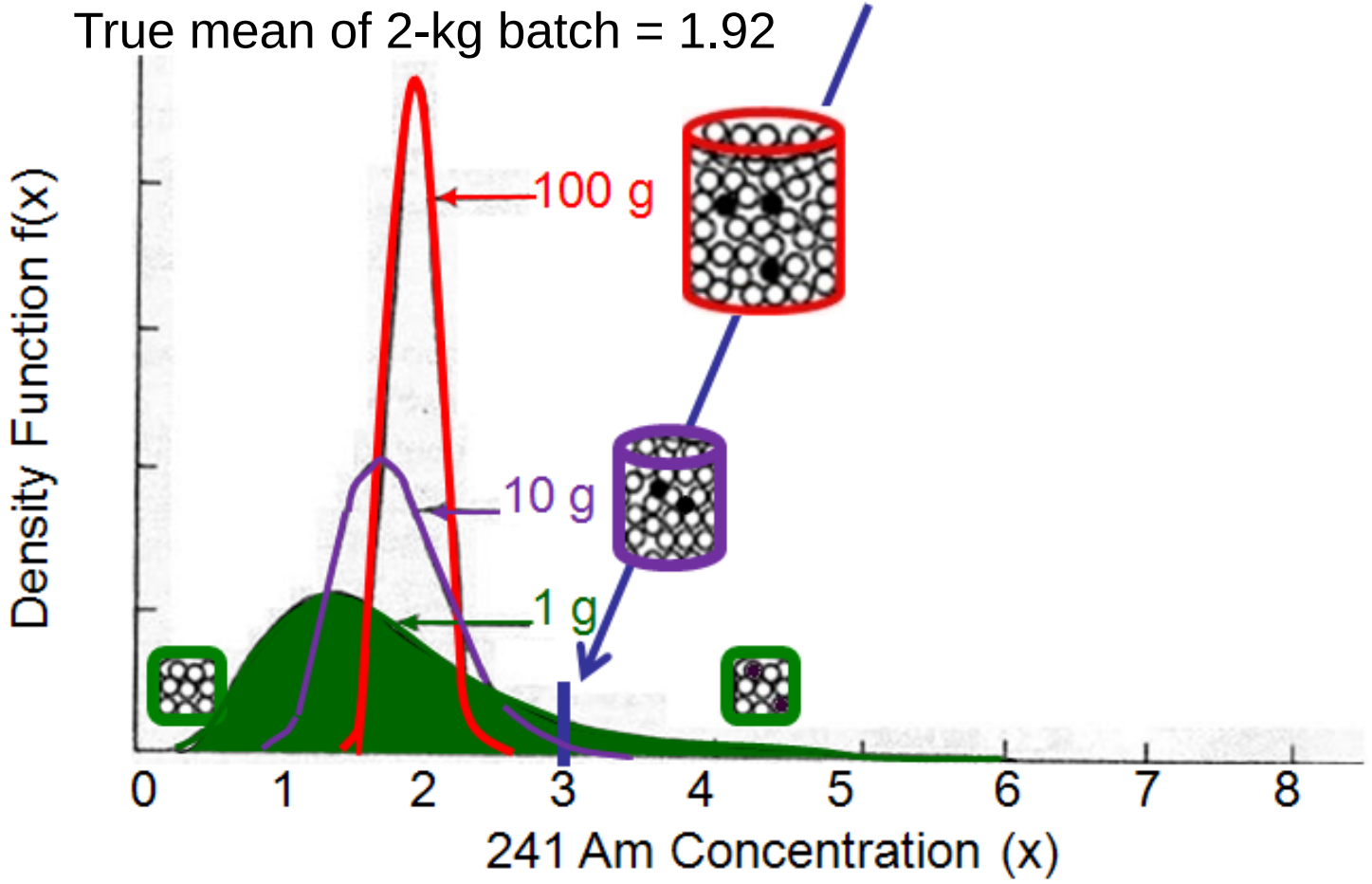


- Decision Error: a decision that would have been made differently if the true condition were known
- Can occur when conclusions are based on data that were significantly influenced by heterogeneity

ITRC, ISM-1, Section 2.4.1.3 and 2.4.2

Skewed Data Distributions Promote Decision Errors

Suppose 3 is an action level. The likelihood of single data points exceeding 3 depends on the sample support.



Avoiding Decision Errors

- Pay attention to QC results in the data package!
  - Suspect sampling error due to micro-scale within-sample heterogeneity when
    - Lab duplicates do not “match”
    - Matrix spikes/matrix spike duplicates do not “match”
  - Suspect sampling error due to short-scale between-sample heterogeneity when
    - Co-located samples do not “match”

Avoiding Decision Errors (continued)

- Be wary of making decisions based on a single data point
  - Especially when traditional sample collection and handling is used
- Use ISM in field and lab!
- Ensure ISM work plans spell out procedures to detect and control sampling error

Summary: Principles

- Inadequate management of soil heterogeneity produces highly variable data sets
- The “maximum concentration” notion is meaningless
- Chance data variability can be misinterpreted to represent the “true” condition for large soil volumes
- Misinterpreting data, especially single data points, can lead to costly decision errors
- The “nuts and bolts” of managing sampling error in the field and lab will be presented in Part 2

ITRC, ISM-1, Sections 5, 6, and 7

Heterogeneity Rules!

You Can't Fool Mother Nature

Acknowledge her or be hobbled by the consequences